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Short Synopsis

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Title: Study of Ionic Behavior of Ionosphere – F2 Region Using Satellite Data

DEPARTMENT OF CHEMISTRY

FACULTY OF ENGINEERING & TECHNOLOGY

Submitted by:

Name: **Bindu**
Registration No.: **10019990191**

Supervisor:

Name: **Dr. Anupama Rajput**
Designation: **Prof. , Deptt. of Chemistry, MRIU FBD**

Joint-Supervisor:

Name: **Dr. Dinesh Kr Sharma**
Designation: **Prof. , Deptt. of Physics, MRCE, FBD**

ABSTRACT

Measurement of ion and electron parameters of ionosphere F2 region at an average altitude of ~500 km made by the Indian satellite SROSS-C2 boarded with separate Retarding Potential Analyzers (RPAs) payloads, have given highly informative and useful data set for more than half of 23rd solar cycle over Indian region. Extensive research work has been undertaken with this data-set regarding electron and ion temperature for the purpose of characterization of ionosphere in reference to communication & navigation, seismic activities etc. The present research work has been proposed to examine and analyze the data set obtained from SROSS-C2 for the composition and the total ion density (n_i) of ionosphere F2 region over the Indian (longitude of 65-95^{o}E and latitude of 5-35^{o}N) region at an average altitude of ~500 km. In the proposed research work, the study of behavioral pattern of different ions and effect of local time, season, solar activity, thunderstorm and lightning on above said region of ionosphere are the points of focus. This will enable better understanding of ionosphere with respect to solar activity, geographical locations and phenomenon taking place above and below it.

Key words: Ionosphere, Total ion density, F2 region, SROSS-C2, solar radio flux, 23rd solar cycle.

CONTENTS

S. No.	Description	Page No.
1.	Introduction	1
2.	Literature Review	2
3.	Description of Broad Area	5
4.	Objective of the Study	7
5.	Methodology to be adopted	7
6.	Proposed/expected outcome of the research	8
7.	References	9

1.0 Introduction

The ionosphere is the region of the atmosphere consisting of several layers of ions and free electrons which are formed by the process of ionization. It extends from about 60-70 km above the surface of the Earth to about 1000 km. .

The ionosphere is comprised of three layers viz: D, E, and F layers.

D is the lowermost layer of ionosphere which range from about 60 to 90 km. Ionization in the D layer is low and it disappears after sunset, because of the rapid recombination of ions. Low frequency signals are refracted by this layer whereas high frequency signals pass right through it and are attenuated.

The E layer extends from about 90 to 170 km. It is also known as the Kennelly- Heaviside layer after the name of its proposers. This layer disappears almost by midnight because of rapid rate of ionic recombination after sunset. It is important for communications in ranges of about 1500 miles since it can refract the signals of frequency as high as 20 megahertz.

The F layer starts from about 170 km onwards. During the daytime, this layer further separates into two layers, F1 (the lower layer) and F2 (the upper layer). The degree of ionization in these layers is high and varies widely throughout the day with the position of sun. Position of the sun influences the characteristics of these layers in the ionosphere and their height above the Earth. The degree of ionization is maximum at noon-time, as sun is at its peak at this time and this layer of the ionosphere is relatively closest to the sun. Recombination takes place slowly after sunset because atmosphere is rarefied at these heights. But, charge particle number density never drops below $10^3 cm^{-3}$ even at night hours.

Ionospheric characteristics like electron & ion temperature, density, and ionic composition depends primarily on the sun and other related phenomenon but show variation with time

(diurnal, seasonal, annual and solar cycle variations), geographical location (latitude & longitude) and with certain solar-related phenomena like solar ionizing flux, energetic charged particles and the electric fields imposed via the interaction between the solar wind, magnetosphere and ionosphere. Some other but important phenomenon like seismic activities (Pulinets & Boyarchuk et al. 2004), thunderstorm, and lightening (Sharma & Rai et al. 2003) are also reported to make noticeable effects on ionospheric parameters.

2.0 Literature Review

Brace and Theis (1978) made use of electron temperature and ion density measured by Langmuir probes onboard the Atmosphere Explorer-C satellite (launched in December 1973) and gave an inter relationship of electron temperature & density in the daytime thermosphere at solar minimum by an empirical model.

Hoegy & Grebowsky et al. (1991) studied the altitude profile of ion composition during 1970-1980, using data base from two different satellite missions, Orbital Geophysical Observatory-6 (OGO-6) and Atmosphere Explorer–C (AE-C); and on the basis of that evaluated some aspects of various theoretical and empirical models including International Reference Ionosphere-90 (IRI-90). The group revealed a significant difference in modeled values and experimental measurements for most of the ions at all altitudes particularly during different solar activities.

Bhuyan & Kakoty (2002) discussed the theoretical simulation of O^+ and H^+ ion density in the Indian low latitude topside ionosphere and compared the result with values made by Indian SROSS C2 satellite and with values predicted by IRI for the period of equinox of solar minimum, 1995-1996. In their studies they found that modeled values were in good accord with satellite observations. IRI speculated higher concentration for H^+ than modeled and satellite values but O^+ concentration was in compliance with them. O^+ / H^+ transition height,

which varies with a number of factors, plays an important role on ionosphere and its properties (Heelis & Coley et al. 2009; Kutiev & Heelis et al. 1980; Brinton & Mayr et al. 1970)

Later on Bhuyan & Bogohain et al. (2007) gave the theoretical simulation of electron density and temperature distribution and compared the results with data measured in situ by Indian SROSS C2 satellite for a period of low solar activity at an altitude of ~ 500 km over Indian equatorial and low latitude ionosphere. They succeed to simulate Equatorial Ionization Anomalies of electron density, morning and evening overshoots, diurnal features of ionosphere and other parameters in close proximity of accuracy by solving the equations for plasma continuity, momentum and energy balance. Bhuyan et al. have done a variety of work with SROSS C2 dataset.

Truhlik & Triskova et al. (2003) gave a global empirical model of relative ion compositions (O^+, H^+, He^+, N^+) in the outer ionosphere in an altitude range of 500-2500 km. In fact a plenty of empirical modeling work has been done by other researchers also in this area (Triskova & Truhlik et al.2003) to make a better understanding of outer ionosphere.

Sharma et al. (2003, 2004) studied the ionosphere w.r.t. the phenomena occurring below and above it over Indian subcontinent region at an altitude of 425-625 km using the dataset obtained from Indian satellite, SROSS-C2. They found the enhancement in average electron and ion temperature by 1.1-1.7 times over the normal days during thunderstorm activity however electron temperature show slightly higher enhancement than that of ion temperature for the same period. They reported the possibility of ULF / VLF radiations generated during thunderstorm to be the probable reason of enhancement in electron and ion temperature. Both lightning and thunderstorm are reported to make remarkable effects on ionosphere (Rai & Rao et al. 1972; Pasko & Inan et al. 1995)

Sharma & Rai et al. (2005) analyzed the ionospheric anomalies related to seismic events, using SROSS - C2 satellite data and reported the enhancement in average ion temperature by 1.2 times over the normal day average ion temperature during the occurrence of earthquake. Joule heating induced by seismogenic vertical electric field propagation, up to ionospheric heights reported to play a significant role in the ion temperature enhancement.

Singh & Singh et al. (2007) examined the critical frequencies (*f*oEs and *f*oF2) for the night time ionospheric E- and F-region for the periods when major earthquakes (6<M<6.6) occurred in Indian seismic zones. Their results showed that *f*oF2 were reduced from their monthly median in both pre-midnight (18:00-00:00 h LT) and post-midnight (00:00-06:00 h LT) time zones prior to the occurrence of main shock. The pre-midnight reduction was slightly higher (24 to 30%) than the post-midnight reduction (18 to 26%). However *f*oEs was found to be enhanced by 100 to 155% under the same conditions. Such earthquake related anomalies can probably be linked with electromagnetic coupling of lithosphere and ionosphere over seismic zone. Many researchers worldwide has contributed towards ionospheric effects of seismic activities (Ondoh 1998; Pulinets 1998; Hayakawa 2004;)

Aggarwal & Joshi et al. (2009) studied the electron and ion temperatures morning overshoot during the sunrise at 500 km altitude (average) using the data set obtained from SROSS C2 satellite. They found that for winter season the morning (around 6:00 LT) overshoot was high (~4000 K) during low solar activity. For summer season, morning (around 5:30 LT) overshoot was higher during moderate solar activity than low solar activity period.

Coley& Holt et al. (2010) measured ion temperature and ion density for the deepest solar minimum of 2008 using dataset obtained from in situ measurement of Communication / Navigation Outage Forecast System (C/NOFS). They compared their observations with IRI

predictions and with incoherent scatter radar measurements from Jicamarca. IRI predictions for ionospheric densities were found higher by a factor of 2-4 than actual measured values; however Jicamarca measurements were in good agreement with C/NOFS observations.

3.0 Description of Broad Area

3.1 Ionization

Primary and fundamental source of ionization at ionosphere is sun and its activity. The electromagnetic radiations (with varying frequencies) coming out from sun reach to different levels of ionosphere and cause ionization to varying extent. D layer being the lowermost has lowest charge density whereas F layer shows the maximum charge density region. Ionospheric structure and peak number densities varies with time (solar cycle, annual, seasonal, and diurnal variations), geographical location and with certain solar-related phenomena like solar ionizing flux, energetic charged particles and the electric fields imposed via the interaction between the solar wind, magnetosphere and ionosphere. Rotation of earth around the sun affects considerably the structure and composition of ionosphere. Sun is the major contributor of ionization towards the earth's ionosphere. There appears to be only one ionospheric layer with a definite peak, namely F2; the other layers merely correspond to changes in electron density gradient.

F2 region is more eratic and sensitive to solar activity. The F2 peak, which represents the maximum electron density in ionosphere, is usually taken as being at 300 km but may vary in altitude between about 200 km and 400 km.

Concentration of constituent ions varies with the height profile of ionosphere. Molecular ions like N_2^+, NO^+ and O_2^+ diminishes at altitudes beyond 300 km. However O_2^+ is a minor

constituent at altitude ~ 500 km (Borgohain & Bhuyan, 2010). Atomic ions like He^+, H^+ and O^+ show their remarkable presence at higher altitudes. H^+ and O^+ dominate at altitude ~ 500 km. At further higher altitudes, beyond H^+ and O^+ transition heights only H^+ dominates.

Other than solar radiations there are sources like GCR & SCR, radiations emitted from radioactive elements, thunderstorm & lightning, volcanoes and seismic activities etc. which play an important role in ionization.

3.2 Day Time Production of Ions in Upper Ionosphere

In the day time primary source of ions and electrons in F region is soft X-ray and extreme ultraviolet radiations from the sun, at wavelength below about 102.7 nm. Molecular oxygen is ionized by Lyman-β (102.6 nm) and shorter wavelength radiation, atomic oxygen is ionized below 91.04 nm, molecular nitrogen below 79.58 nm and atomic nitrogen below 85.31 nm. Atomic nitrogen is not, however an important source of ions because its concentration is small in comparison with those of N_2, O_2 and O around 200 km.

3.3 Night Time Production of Ions in Upper Ionosphere

Charge density in F region never drops below 10^3 cm^{-3}. The observed persistence of many atmospheric ions such as N_2^+, O_2^+ (at low altitudes), H^+ and O^+ (at high altitude) at night also implies the presence of an ionizing source of sufficient energy. The exact nature of this source has not been established. Occurrence of Lyman-α line in the nightglow, X-ray emission from stars and cosmic rays are few suggested source for night time ionization.

4.0 Objectives of Study

The main objective of present study is to chemically characterize upper ionosphere-F2 region over the Indian region (longitude of 65-95°E and latitude of 5-35°N) at an average altitude of ~500 km. This region will be studied with the following objectives.

- To evaluate different ion characteristics, their abundance and their behavioral pattern with respect to different variables like time, season, location etc.
- To study the effect of solar activity on ionosphere in terms of solar flux ($F_{10.7}$) since F-2 region has high importance for communication and navigation.
- To study the effect of thunderstorm on this region of ionosphere.
- To study the effect of lightning on this region of ionosphere.

Note: All studies will be done with respect to ion characteristics of above mentioned region of ionosphere.

5.0 Methodology

During the proposed research work the satellite data will be analyzed for the above said objectives. The Indian satellite Stretched Rohini Satellite Series (SROSS) - C2 was launched on May 4, 1994 with the help of rocket, Augmented Satellite Launch Vehicle - D4 (ASLV-D4) in an orbit of 625×425 km and 46° inclination. Aeronomy payload of RPA, was onboard the satellite SROSS-C2 for making F2 region in situ measurements of ionospheric ion and electron parameters separately over Indian region. The satellite provided important and useful data for more than half of 23rd solar cycle covering solar minimum (1995) as well as solar maximum (2000). SROSS-C2 was spin stabilized satellite with its spin axis oriented normal to the orbital

plane at a spin rate of 5 rpm, octagonal prismoid in shape with eight body mounted solar panels. The two RPA sensors consist of mechanically identical four grids viz: entrance grid, retarding grid, suppressor grid, collector shield grid and a collector electrode with different grid voltage. Only those electrons and ions which have energy, greater than threshold energy, made pass through various grids and finally collected at collector electrode. Data for O^+, O_2^+, H^+ and He^+ ions was derived from ion RPA throughout the experiment. Some more aspects of aeronomy experiments have been discussed by Garg & Das (1995).

- The earlier research work carried out Bhuyan et al. (2002 & 2006), Sharma et al. (2003 & 2004), and Aggarwal & Joshi et al. (2009) etc. with SROSS-C2 satellite data will be taken as base for further study.
- To study the variation in ionospheric characteristic, local weathering data (if required) can be procured from Indian Meteorological Department.
- The data over desired region will be extracted and analyzed for the above said parameters under given set of conditions.
- Ionospheric models like International Reference Ionosphere (IRI) can also be consulted at instances to maintain the accuracy and for comparison of results.

6.0 Proposed / Expected outcome of research

The proposed research work will come out with the chemical structure of F-2 region of ionosphere.

- It will reveal the different ions present, their characteristics and their variation with many factors like time, season, location etc.

- After this research ionospheric effects of solar activity in terms of solar flux ($F_{10.7}$) (in the specified region) will be clear.
- Effects of thunderstorm with respect to ion characteristics of ionosphere F-2 region will be understood.
- Lightening effects on the Indian ionospheric region will be established.

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